



Biomass gasification-based syngas production for a conventional oxo synthesis plant—greenhouse gas emission balances and economic evaluation



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ARTICLE INFO

Article history:

Received 1 September 2014
Received in revised form
12 February 2015
Accepted 2 March 2015
Available online 11 March 2015

Keywords:

Biomass gasification
Syngas production
Process integration
Oxo synthesis plant
GHG emission reductions
Process economics

ABSTRACT

The long-term primary option for the chemical industry to reduce fossil feedstock dependence and greenhouse gas emissions is to switch to a renewable feedstock. This study investigates the global greenhouse gas emission balances and process economics of switching the natural gas-based syngas feedstock of a conventional oxo synthesis plant to a biomass-based feedstock. Two biomass gasification-based concepts are considered: (i) replacing the natural gas with biomass-derived synthetic natural gas; and (ii) replacing the syngas directly with biomass-derived syngas. The work is based on previously conducted work by the authors in which process modeling, integration opportunities, and the thermodynamic performance of the proposed biomass-based concepts were investigated. The assessment approach is to compare two different biomass-based process routes to the same end-product by switching the introduction point in the fossil-based process value chain. The different concepts are compared in terms of greenhouse gas emission reduction potential and change in production cost of oxo products compared with the conventional route. A system boundary expansion approach is applied to estimate the global greenhouse gas emission balances, thus eliminating the need to define the final use of the oxo product. Sensitivity analyses are conducted with respect to future material and energy prices, carbon dioxide emission charges, capital cost estimations, and reference grid electricity generation technologies. The direct biomass-based syngas route is shown to achieve promising environmental and economic performance levels. The results indicate that producing biomass-based syngas directly can be economically competitive with natural gas-based syngas for price projections based on current policies. However, for future policies associated with major greenhouse gas emission constraints, no direct economic incentive for switching to biomass-based syngas production is achieved. These results suggest that policy measures other than a carbon dioxide emission charge can be necessary to achieve a transition to renewables for the production of oxo products.

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1. Introduction

The chemical industry is an energy-intensive sector and, moreover, heavily dependent on fossil feedstock. In 2011, approximately 10% of the total global final energy demand was related to the use of energy and feedstock in this sector (IEA, 2014). A trend to switch from liquid or solid to gaseous feedstock and fuels can be observed in the chemical industry (IEA, 2012a). However, the

transition to natural gas (NG) only offers a short-to medium-term solution, since it is a finite fossil resource that contributes to an increased concentration of atmospheric greenhouse gases (GHGs) upon combustion (although approximately 40% and 15% less per unit of energy content compared with coal or oil, respectively (Gode et al., 2011)). Moreover, some of the methods of NG extraction (e.g., hydraulic fracturing in shale rock formations) are associated with environmental and social concerns.

In addition to increasing the energy efficiency, other options to reduce GHG emissions in the chemical industry are needed (Gielen et al., 2002). The primary long-term option to reduce fossil feedstock dependence and GHG emissions in the chemical industry is to

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Abbreviations

ASU	Air Separation Unit;
Bio-SNG	Biomass-derived Synthetic Natural Gas;
BioSNG2Syngas	biomass-based syngas production via bio-SNG system;
Bio2Syngas	biomass-based syngas production system;
Case EI	heat recovery option with maximized electric power generation;
Case LP	heat recovery option with Low-Pressure (LP) steam (co-)generation;
CCS	Carbon Capture and Storage;
Coal PP	Coal Power Plant;
CO _{2,eq}	CO ₂ equivalents calculated according to GWP ₁₀₀ method;
DME	DiMethyl Ether
GHG	GreenHouse Gas;
GWP ₁₀₀	Global Warming Potential for a 100 year period;
HHV	Higher Heating Value;
HP	High-Pressure (41 bar(a));
IEA	International Energy Agency;
LP	Low-Pressure (3 bar(a));
NG	Natural Gas;
O&M	Operation and Maintenance;
RME	Rapeseed Methyl Ester;
WEO	World Energy Outlook (annual IEA publication).

switch to renewable feedstock. The International Energy Agency (IEA) has identified biomass-based technologies as important future “game changers” for the chemical industry to reduce dependence on fossil feedstock and GHG emissions (IEA et al., 2013). The IEA's definition of a biorefinery is “the sustainable processing of biomass into a spectrum of marketable products (food, feed, materials, chemicals) and energy (fuels, power, heat)” (IEA, 2012b).

1.1. Background

The supply of energy and transportation fuels have been the main focus for ongoing research projects related to the transition to renewables, as well as for the political arena in terms of visionary goals and policy instruments. In contrast to the supply of heat and power and to a certain extent transportation energy needs, where a number of promising alternative technologies for harnessing non-carbon-based renewable energy sources have been developed, the production of chemicals and materials requires a source of carbon. Accordingly, biomass appears the most relevant renewable option for these commodities. Although biomass is renewable, it must be considered as a limited resource in the future, which stresses the importance of efficient utilization. Moreover, it must be ensured that the transition to renewables is related to a transition to sustainable systems and processes. The environmental performance of the biomass-based production of chemicals is essential to assess, as well as the economic performance.

There are several possible routes to convert biomass, including chemical, biochemical, thermochemical, and mechanical routes. The development of the bio-chemical and chemical conversion of easily accessible carbohydrates (such as sugar- or starch-based biomass) to high-value fine or specialty chemicals has received significant attention. A number of biomass-based chemical and material production sites exist at commercial scale, e.g., corn-

based polylactic acid (PLA) in the USA (NatureWorks LLC, 2014) and ethylene from sugarcane-based ethanol in Brazil (Braskem, 2014).

Effective integration into existing industry is considered a key factor for a successful transition to a bio-based economy, according to the IEA (IEA, 2012b). The easiest market penetration is expected to be achieved with drop-in bio-chemicals. van Haveren et al. (2008) highlighted the advantages of producing biomass-based chemicals for substitution of platform and bulk chemicals in the current fossil-based petrochemical industry using the port of Rotterdam in the Netherlands as a case study. Six important platform chemicals were identified as feasible (ethylene, propylene, C4-olefins, benzene, toluene, and xylene). Routes based on syngas or pyrolysis oil were not included. The infrastructure of the current petrochemical industry was also used to investigate the opportunities, perspectives, and potentials for the production of platform chemicals from lignocellulosic biomass (primarily via biochemical processes) in an analysis by Cherubini and Strømman (2011). For the synthesis of short-carbon-chain chemicals such as ethylene and propylene, thermochemical conversion was highlighted as a particularly promising route.

Thermochemical gasification is considered to be a promising technology for the conversion of lignocellulosic biomass, such as forest residues. During thermochemical gasification, a carbonaceous feedstock is converted into raw syngas, mainly consisting of H₂, CO, CO₂, and CH₄, which can be further processed into a spectrum of possible products. Syngas produced from biomass has physical and chemical characteristics similar to conventional fossil-derived syngas, thus allowing for relatively easy integration of gasification-based biorefinery concepts with existing fossil syngas-based facilities. The market for syngas and derivatives is expected to grow according to a recent market tracker report that identifies global trends and forecasts to 2018 (MarketsandMarkets, 2013). Methanol, ammonia, hydrogen, oxo chemicals, n-butanol, and dimethyl ether (DME) are the syngas derivatives discussed in the report. For the future production of chemicals and fuels, biomass and waste utilization (as well as underground coal gasification) are noted as major opportunities.

Process integration studies of various thermochemical biorefinery concepts at different industrial sites have been reported in the literature, such as at a biomass-fired combined heat and power plant (Heyne et al., 2012); pulp and paper mills (Andersson and Lundgren, 2014; Consonni et al., 2009); a mechanical pulp and paper mill co-located with a sawmill plant (Isaksson et al., 2012); a steel plant (Johansson, 2013; Lundgren et al., 2013); a chemical cluster (Holmgren et al., 2014); and oil refineries (Brau et al., 2013; Johansson et al., 2012; Sadhukhan and Ng, 2011). Oxo synthesis is another possible interesting application of biomass-derived syngas (Boerrigter and Rauch, 2006; Spath and Dayton, 2003). To the authors' knowledge, no detailed study of the integration of gasification-based biorefinery concepts in oxo synthesis plants has been conducted.

Current research on biomass gasification-based chemicals production focuses on bulk chemical production such as methanol and hydrogen, to be used as final products (e.g., transportation purposes) or as platform chemicals (e.g., production of olefins or ammonia). The production of DME (that e.g., could be produced via methanol dehydration) has also been studied for the aforementioned applications. The objectives of the studies include benchmarking technologies (Ciferno and Marano, 2002); reviewing potential routes (Haro et al., 2013a); conducting techno-economic assessments (Hamelinck and Faaij, 2002; Hannula and Arpiainen, 2014; Haro et al., 2013b); or combining techno-economic and carbon accounting assessments (Gilbert et al., 2014).

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